# PHYSICAL PROPERTIES OF SOME TOXIC SOLUTIONS

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This paper deals with the osmotic pressure and the surface tension of (1) water obtained from sphagnum bogs of the Puget Sound region and Alaska, (2) solutions obtained by allowing the rhizomes of *Nymphaea polysepala* Gr. to decay in water.

## Osmotic pressure

The difference between the freezing point of each solution and that of pure water was determined with the Beckman apparatus. From this lowering, the osmotic pressure at 0° C. was calculated in two ways: (1) from a consideration of the relation between molar concentration and osmotic pressure[1] established directly by Morse (6); (2) by substitution in the ordinary formula based on thermodynamic reasoning, namely, $P=12.05\times dt$ atmospheres at 0°.

TABLE I

Osmotic pressure of bog waters

| Sources | Sample obtained | Sample tested | $dt$ | $P$ (Morse) | $P$ (Nernst) | $M$ |
|---|---|---|---|---|---|---|
| 1. Henry bog sample 1.. | Dec. 22, 1914 | Jan. 19, 1915 | 0.008 | 80.48 | 73.15 | 0.004301 |
| 2. Henry bog sample 2.. | Dec. 22, 1914 | Jan. 21, 1915 | 0.008 | 80.48 | 73.15 | 0.004301 |
| 3. Maltby bog sample 1. | Feb. 22, 1915 | Mar. 3, 1915 | 0.008 | 80.48 | 73.15 | 0.004301 |
| 4. Maltby bog sample 2. | Feb. 22, 1915 | Mar. 3, 1915 | 0.008 | 80.48 | 73.15 | 0.004301 |
| 5. South Mud Lake bog. | Mar. 6, 1915 | Mar. 13, 1915 | 0.009 | 90.55 | 82.40 | 0.004839 |
| 6. Henry bog.......... | Feb. 23, 1915 | Mar. 13, 1915 | 0.000 | ........ | ........ | ......... |
| 7. Cordova (Alaska) bog. | May 23, 1913 | Mar. 13, 1915 | 0.006 | 60.37 | 54.94 | 0.003226 |
| 8. North Mud Lake bog. | Mar. 13, 1915 | Mar. 27, 1915 | 0.002 | 20.12 | 18.31 | 0.001074 |
| 9. Fauntleroy bog ...... | Aug. 30, 1915 | Sept. 7, 1915 | 0.002 | 20.12 | 18.31 | 0.001074 |
| 10. North Mud Lake bog. | Sept. 1, 1915 | Sept. 7, 1915 | 0.002 | 20.12 | 18.31 | 0.001074 |
| 11. Henry bog.......... | Aug. 28, 1915 | Sept. 7, 1915 | 0.003 | 30.18 | 27.46 | 0.001611 |
| 12. South Mud Lake bog. | Sept. 1, 1915 | Sept. 7, 1915 | 0.004 | 40.25 | 36.63 | 0.002148 |

In table I, $dt$ represents the lowering of the freezing point in degrees centigrade; $M$ represents the molar concentration of a solution of any non-electrolyte which shows the same lowering of the freezing point; $P$ represents the osmotic pressure in millimeters

[1] These investigators found that 0.1 M sugar solutions at 0° C. give 2.462 atmospheres osmotic pressure. This corresponds to 0°.186 depression of the freezing point.

of mercury. The data are put into such form that they may be compared with the data given by LIVINGSTON (5) for bog waters of central and eastern United States.[2]

Duplicate series of determinations of the freezing point lowering were made for each sample reported in table I. Owing to the low concentrations of the solutions, the maximum or freezing-point temperatures remained surprisingly constant, and were read at one-minute intervals from 6 to 10 times. The deviation from the mean in each series was usually about 0°001, seldom as high as 0°002, the estimated reading error of the thermometer. The means of the two series agreed with each other in all cases within 0°001, and in four cases they were identical. A hand lens (aplanatic triplet) was used in reading the scale, and care was taken to avoid parallax. The temperature of the outer bath in all of the tests except 3 was between 3°5 C. and 3°8 C. In the three exceptions the temperatures were 3°4, 4°0, and 4°5 C.

Samples 1–8 inclusive were obtained during the rainy season or soon after its close. Each sample was obtained by cutting out the sphagnum to a depth of 30–45 cm. and dipping up the water that collected. Samples 9–12 were obtained just at the close of the dry season. Samples 9 and 11 were obtained by squeezing the water from handfuls of sphagnum obtained at 50–200 mm. below the surface of the bog. This method was used because at that time no water accumulated in a hole 1.5 m. deep in half an hour. Samples 10 and 12 were dipped up from holes cut in the sphagnum 40 cm. deep. In both of the Mud Lake bogs the height of the water table is evidently determined by the level of the adjoining lake. There is no lake adjoining either the Fauntleroy bog or the Henry bog.

The general characteristics of the sphagnum bogs of the Puget Sound region and of the Alaska coast have been described by RIGG (**7, 8**). Descriptions of the Henry bog, the Fauntleroy bog, and the Cordova bog are included in the papers cited. Maltby bog is situated in Snohomish County, Washington, about a mile

[2] LIVINGSTON'S osmotic pressures are computed for 25° C.; those of the writers' are for 0° C., hence should be multiplied by $\frac{298}{273}$ for comparison with LIVINGSTON'S pressures.

south of the town of Maltby. It has an area of some 60 acres. Mud Lake is situated on the west side of Lake Washington, just north of the city limits of Seattle. It is separated from Lake Washington by a narrow wave-built ridge of gravel. South Mud Lake bog is a small patch of sphagnum situated within the southern portion of the lake. North Mud Lake is larger (perhaps 15 acres in area) and lies adjacent to the north and west sides of the lake.

For comparison, the lowering of the freezing point of the waters from some lakes and springs was determined. The results are shown in table II.

TABLE II

OSMOTIC PRESSURE OF THE WATERS FROM SOME PUGET SOUND LAKES AND SPRINGS

| Sources | Sample obtained | Sample tested | *dt* | *P* (Morse) | *P* (Nernst) | *M* |
|---|---|---|---|---|---|---|
| 1. Crystal Lake | Feb. 22, 1915 | Mar. 3, 1915 | 0.007 | 70.42 | 64.08 | 0.003763 |
| 2. Mud Lake | Mar. 6, 1915 | Mar. 13, 1915 | 0.001 | 10.06 | 9.16 | 0.000537 |
| 3. Lake Washington | Mar. 6, 1915 | Mar. 13, 1915 | 0.002 | 20.12 | 18.31 | 0.001074 |
| 4. Spring no. 1 | Mar. 6, 1915 | Mar. 13, 1915 | 0.000 | ......... | ......... | ......... |
| 5. Spring no. 2 | Mar. 11, 1915 | Mar. 13, 1915 | 0.002 | 20.12 | 18.31 | 0.001074 |
| 6. Mud Lake | Sept. 1, 1915 | Sept. 7, 1915 | 0.004 | 40.25 | 36.63 | 0.002148 |
| 7. Lake Washington | Sept. 1, 1915 | Sept. 7, 1915 | 0.004 | 40.25 | 36.63 | 0.002148 |
| 8. Spring no. 2 | Sept. 1, 1915 | Sept. 7, 1915 | 0.004 | 40.25 | 36.63 | 0.002148 |

Crystal Lake is located in the center of Maltby bog. It is entirely surrounded by sphagnum, and has, at least at the surface, no contact with other soil. The lake has an area of about 10 acres. The water from this lake is scarcely distinguishable in appearance from that of the bog. The location of Mud Lake has already been given. Its water resembles bog water somewhat and contrasts strongly with the clear water of Lake Washington. Samples 3 and 7 were collected from Lake Washington at a point near Mud Lake. Spring no. 1 is just north of the city limits of Seattle. It is near East 65th Street and 40th Avenue N.E. It is in logged-off land which is not under cultivation. Spring no. 2 is at the head of a ravine on an unused portion of the campus of the University of Washington. It is situated in logged-off land.

The difference between the freezing point of pure water and that of solutions resulting from the decay of rhizomes of *Nymphaea polysepala* was also determined with the Beckman apparatus. The

standard solution used was that resulting from the decay of 500 gm. of the rhizome in 800 cc. of water. Table III shows the results of the test on three different solutions thus prepared.

TABLE III

LOWERING OF FREEZING POINT OF STANDARD SOLUTIONS FROM THE DECAY OF *Nymphaea* RHIZOMES IN WATER

| Solution | Date of test | Lowering of freezing point |
|---|---|---|
| 1.................. | Feb. 24, 1915 | 0.097 |
| 2.................. | Feb. 24, 1915 | 0.156 |
| 3.................. | Mar. 13, 1915 | 0.142 |

The osmotic pressure of 10 per cent (1 volume of solution to 9 volumes of water), $7\frac{1}{2}$ per cent, and 5 per cent solutions of these standard solutions was calculated from the results shown in table III. These computed values are shown in table IV.

TABLE IV

CALCULATED OSMOTIC PRESSURES OF SOLUTIONS FROM DECAY

| Solution | *dt* | *P* (Morse) | *P* (Nernst) | *M* |
|---|---|---|---|---|
| Sample 1, 10 per cent..... | 0.010 | 100.63 | 91.6 | 0.005376 |
| Sample 1, $7\frac{1}{2}$ per cent..... | 0.007 | 70.42 | 64.08 | 0.003763 |
| Sample 1, 5 per cent..... | 0.004 | 40.25 | 36.63 | 0.002148 |
| Sample 2, 10 per cent..... | 0.016 | 161.0 | 146.4 | 0.008601 |
| Sample 2, $7\frac{1}{2}$ per cent..... | 0.011 | 110.7 | 100.7 | 0.005913 |
| Sample 2, 5 per cent..... | 0.007 | 70.42 | 64.08 | 0.003763 |
| Sample 3, 10 per cent..... | 0.014 | 140.9 | 128.2 | 0.007527 |
| Sample 3, $7\frac{1}{2}$ per cent..... | 0.010 | 100.6 | 91.6 | 0.005376 |
| Sample 3, 5 per cent..... | 0.007 | 70.42 | 64.08 | 0.003763 |

These particular dilutions are suggested because these (and in some cases greater) dilutions proved toxic to plants grown in them by RIGG (9).

## Surface tension

Tests of the surface tension of bog waters were made by the Jolly method. The results are shown in table V.

TABLE V

SURFACE TENSION OF BOG WATERS

| Liquid | Surface tension in dyne cm. | Surface tension in percentage of surface tension of pure water |
|---|---|---|
| Pure water. . . . . . . . . . . . . . . . | 72.7 | 100 |
| Ronald bog, sample no. 1, unfiltered. . . . . . . . . . . . . . . | 70.3 | 96* |
| Ronald bog, sample no. 2, unfiltered. . . . . . . . . . . . . . . | 72.3 | 99* |
| Ronald bog, sample no. 1, filtered. . . . . . . . . . . . . . . . . | 65.7 | 92* |
| Maltby bog. . . . . . . . . . . . . . . | 67.5 | 94* |

* Computed from the data in column 1 on the basis of the surface tension of pure water given in Smithsonian table no. 141· p. 128. Rev. ed. 1897.

Tests of surface tension by the Jolly method were also made on solutions resulting from the decay of *Nymphaea* rhizomes in water. The standard solution used was that resulting from the decay of 500 gm. of the rhizome in 800 cc. of water. Table VI shows the results of the tests. Unless otherwise noted, the tests are on the standard solution. Dilutions of 10 per cent (9 volumes of water + 1 volume of solution), 7½ per cent, and 5 per cent are so designated in the table.

TABLE VI

SURFACE TENSION OF SOLUTIONS RESULTING FROM THE DECAY OF *Nymphaea* RHIZOMES

| Liquid | Surface tension in dyne cm. | Surface tension in percentage of surface tension of pure water |
|---|---|---|
| Sample 1. . . . . . . . . . . . . . . . . . . . . . . | 64.2 | 88.0 |
| Sample 1 diluted to 10 per cent. . . . | 66.9 | 93.0 |
| Sample 1 diluted to 7½ per cent. . . . | 73.1 | 101.0 |
| Sample 1 diluted to 5 per cent. . . . . | 72.3 | 99.0 |
| Sample 2. . . . . . . . . . . . . . . . . . . . . . . | 60.6 | 84.0 |
| Sample 3. . . . . . . . . . . . . . . . . . . . . . . | 62.9 | 87.0 |

In order to compare surface tension results obtained by the writers by the Jolly method with the results obtained by CZAPEK (3) with his apparatus, a series of alcohols were tested.

The results are compared in table VII. The first two columns show the writers' results, while the third shows CZAPEK'S results.

TABLE VII

SURFACE TENSION OF ALCOHOLS

| Alcohol | Surface tension in dyne cm. | Surface tension in percentage of surface tension of pure water | Surface tension from Czapek |
|---|---|---|---|
| 7 per cent ethyl.......... | 55.7 | 76 | 76 |
| 13 per cent ethyl.......... | 48.9 | 67 | 65 |
| 15 per cent ethyl.......... | 45.6 | 63 | 62 |
| 15 per cent methyl........ | 53.1 | 73 | 73 |
| 20 per cent methyl........ | 45.6 | 64 | 67 |

The surface tension of 13 per cent ethyl alcohol was tested with a duplicate of CZAPEK'S apparatus. The average of the tests made was 66, which lies between the results given by CZAPEK and the results obtained by the writers with the Jolly apparatus. It was thought best to use the Jolly apparatus rather than this duplicate of CZAPEK'S apparatus, since in general more dependable results would thus be obtained. There are at least three sources of error in CZAPEK'S apparatus: (1) the difference in the height of the water in the two sides of the manometer cannot be read any closer than 1 mm., owing to the irregular meniscus and the necessity of taking the readings just as a sudden change of height is taking place; (2) the capillary tube is immersed so slightly in the liquid that a small error in the depth to which it is immersed would make a relatively large error in the result; (3) it is an indirect method, the value for each liquid being compared with the value for pure water determined with the same apparatus, thus giving a double chance for error.

## Discussion

LIVINGSTON (5) has published data which he summarizes as follows: "bog waters do not have an appreciable higher concentration of dissolved substances than do the streams and lakes of the same region." The following are the averages of the results of all tests of the lowering of the freezing point of bog waters and of other surface waters reported by LIVINGSTON (*loc. cit.*), and of

the results of all tests made by the writers on such waters: LIVINGSTON's tests on bog waters, 0.009; tests by the writers on bog waters, 0.005; LIVINGSTON's tests on other surface waters, 0.007; tests by the writers on other surface waters, 0.003. In so far as the data given can be taken to be representative of the regions, it seems that the osmotic pressure of all waters tested is lower in the region worked in by the writers than in the region in which LIVINGSTON worked. The difference between the average for bog waters and for other surface waters in the two regions is exactly the same.

LIVINGSTON (*loc. cit.*) found "practically no difference in osmotic pressure corresponding to the season." The average of the determinations made by the writers on bog waters during the rainy season and during the dry season is as follows: rainy season, 0.006; dry season, 0.002. Here, as elsewhere in this paper, figures beyond the third place are not considered significant.

FITTING (4) has concluded that xerophytism and difficulty in absorption do not seem to be correlated with high osmotic pressure (the writers have not seen this paper).

Whatever conclusions the writers would be justified in drawing from their data would be in substantial agreement with those of LIVINGSTON and of FITTING. That is, high osmotic pressure is not the cause of the toxicity of the waters of sphagnum bogs.

Omitting Crystal Lake (since the properties of its waters seem practically identical with those of bog waters), the comparison of the lowering of the freezing point of lake and spring waters for the wet season and the dry season[3] is as follows: average for the wet season, 0.001; average for the dry season, 0.004. This is too small a number of tests to be made the basis of any generalization as to seasonal variation in osmotic pressure in this region. The average of the limited data here cited, however, is just the opposite of the average of the data secured by TRANSEAU (11) for central Illinois in 1913, when there were no rains of consequence from the middle of April to the middle of September. He found that the highest osmotic pressures were recorded during the spring, when the water levels were highest, and that the lowest records were during the

[3] There was no rain for 45 days preceding the time of collection of the samples for the dry season.

middle of September, when the levels for the year were the lowest. He found that the osmotic pressure of the waters tested (expressed in mm. of mercury) varied from 59 to 407. Those tested by the writers (table II) varied from 0 to 70. The waters of the Puget Sound region are soft, possessing very little of even temporary hardness.

In so far as the data given in this paper are concerned, the seasonal variation of osmotic pressure in the waters of the sphagnum bogs in the Puget Sound region seems to be the opposite of that of the waters of springs and lakes.

The surface tension of bog water was measured in order to determine whether it might be low enough to cause exosmose from the root cells of plants growing in the bogs. BLACKMAN (1) and CZAPEK (2) find that when liquids having a surface tension of 0.66 or less (pure water being taken as 1.00) are applied to plant cells most of the cells are injured and die. The results shown in table III show surface tensions so far above 0.66 that there seems to be no reason whatever for supposing that low surface tension could be a factor in the toxicity of the waters of sphagnum bogs.

It has been noted in the field by SHERFF (10) that rhizomes of *Sagittaria* are killed when they grow into the decaying portion of the rhizomes of *Nymphaea advena*. It has also been found by RIGG (*loc. cit.*) that solutions resulting from the decay of *Nymphaea* rhizomes are toxic to *Tradescantia* cuttings and to agricultural plants, even in very dilute solution.

There is no indication in the data here published that either high osmotic pressure or low surface tension can be a factor of any importance in the toxicity of the solutions resulting from the decay of *Nymphaea* rhizomes in the extreme dilutions which proved toxic to *Tradescantia* cuttings and to agricultural plants.

## Summary

1. The osmotic pressure of bog water in the samples tested was higher during the rainy season than at the close of the dry season.

2. The osmotic pressure of the waters tested from lakes and springs was lower during the rainy season than at the close of the dry season.

3. There is no indication that either high osmotic pressure or low surface tension is an important factor in the toxicity of bog water or of very dilute solutions resulting from the decay of *Nymphaea* rhizomes.

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